

## PATENT COOPERATION TREATY

PCT

## NOTIFICATION OF ELECTION

(PCT Rule 61.2)

From the INTERNATIONAL BUREAU

To:

United States Patent and Trademark  
Office  
(Box PCT)  
Crystal Plaza 2  
Washington, DC 20231  
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

<b>Date of mailing</b> (day/month/year) 27 April 1998 (27.04.98)	<b>Applicant's or agent's file reference</b> FP2136(a)
<b>International application No.</b> PCT/GB97/02388	<b>Priority date</b> (day/month/year) 10 September 1996 (10.09.96)
<b>International filing date</b> (day/month/year) 05 September 1997 (05.09.97)	
<b>Applicant</b> MAYES, Ian, Christopher et al	

1. The designated Office is hereby notified of its election made:

☒ in the demand filed with the International Preliminary Examining Authority on:  
31 March 1998 (31.03.98)

☐ in a notice effecting later election filed with the International Bureau on:

2. The election ☒ was  
☐ was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO  
34, chemin des Colombettes  
1211 Geneva 20, Switzerland

Facsimile No.: (41-22) 740.14.35

Authorized officer

I. Britel

Telephone No.: (41-22) 338.83.38

## PATENT COOPERATION TREATY

PCT

NOTIFICATION OF THE RECORDING  
OF A CHANGE(PCT Rule 92bis.1 and  
Administrative Instructions, Section 422)

From the INTERNATIONAL BUREAU

To:

MARKGRAAF PATENTS  
The Crescent  
54 Blossom Street  
York YO2 2AP  
ROYAUME-UNI

Date of mailing (day/month/year) 08 May 1998 (08.05.98)	<b>IMPORTANT NOTIFICATION</b>
Applicant's or agent's file reference FP2136(a)	
International application No. PCT/GB97/02388	International filing date (day/month/year) 05 September 1997 (05.09.97)

## 1. The following indications appeared on record concerning:

☒ the applicant      ☒ the inventor      ☐ the agent      ☐ the common representative

Name and Address YUN HENG CHIN Freddie Bio-Rad House Maylands Avenue, Hemel Hempstead Hertfordshire HP2 7TD United Kingdom	State of Nationality MY	State of Residence GB
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

## 2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:

☒ the person      ☒ the name      ☒ the address      ☒ the nationality      ☒ the residence

Name and Address YUN HENG CHIN Freddie Bio-Rad House Maylands Avenue, Hemel Hempstead Hertfordshire HP2 7TD United Kingdom	State of Nationality MY	State of Residence GB
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

## 3. Further observations, if necessary:

The person listed above has been added as applicant and inventor for the US. HIGGS Victor is the lead inventor and his name should appear first on the patent.

## 4. A copy of this notification has been sent to:

<input checked="" type="checkbox"/> the receiving Office	<input type="checkbox"/> the designated Offices concerned
<input type="checkbox"/> the International Searching Authority	<input checked="" type="checkbox"/> the elected Offices concerned
<input checked="" type="checkbox"/> the International Preliminary Examining Authority	<input type="checkbox"/> other:

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland  Facsimile No.: (41-22) 740.14.35	Authorized officer  I. Britel  Telephone No.: (41-22) 338.83.38
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## PATENT COOPERATION TREATY

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From the INTERNATIONAL BUREAU

NOTIFICATION OF THE RECORDING  
OF A CHANGE(PCT Rule 92bis.1 and  
Administrative Instructions, Section 422)

To:

MARKGRAAF PATENTS  
The Crescent  
54 Blossom Street  
York YO2 2AP  
ROYAUME-UNI

Date of mailing (day/month/year) 08 May 1998 (08.05.98)	IMPORTANT NOTIFICATION
Applicant's or agent's file reference FP2136(a)	
International application No. PCT/GB97/02388	International filing date (day/month/year) 05 September 1997 (05.09.97)

1. The following indications appeared on record concerning:		
<input checked="" type="checkbox"/> the applicant	<input checked="" type="checkbox"/> the inventor	<input type="checkbox"/> the agent <input type="checkbox"/> the common representative
Name and Address SWEENEY Michael Bio-Rad House Maylands Avenue, Hemel Hempstead Hertfordshire HP2 7TD United Kingdom	State of Nationality GB	State of Residence GB
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	
2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:		
<input checked="" type="checkbox"/> the person	<input checked="" type="checkbox"/> the name	<input checked="" type="checkbox"/> the address <input checked="" type="checkbox"/> the nationality <input checked="" type="checkbox"/> the residence
Name and Address SWEENEY Michael Bio-Rad House Maylands Avenue, Hemel Hempstead Hertfordshire HP2 7TD United Kingdom	State of Nationality GB	State of Residence GB
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	
3. Further observations, if necessary: The person listed above has been added as applicant and inventor for the US. HIGGS Victor is the lead inventor and his name should appear first on the patent.		
4. A copy of this notification has been sent to:		
<input checked="" type="checkbox"/> the receiving Office	<input type="checkbox"/> the designated Offices concerned	
<input type="checkbox"/> the International Searching Authority	<input checked="" type="checkbox"/> the elected Offices concerned	
<input checked="" type="checkbox"/> the International Preliminary Examining Authority	<input type="checkbox"/> other:	

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland	Authorized officer I. Britel
Facsimile No.: (41-22) 740.14.35	Telephone No.: (41-22) 338.83.38

## PATENT COOPERATION TREATY

PCT

From the INTERNATIONAL BUREAU

NOTIFICATION OF THE RECORDING  
OF A CHANGE(PCT Rule 92bis.1 and  
Administrative Instructions, Section 422)

To:

MARKGRAAF PATENTS  
The Crescent  
54 Blossom Street  
York YO2 2AP  
ROYAUME-UNI

Date of mailing (day/month/year) 17 April 1998 (17.04.98)	IMPORTANT NOTIFICATION
Applicant's or agent's file reference FP2136(a)	
International application No. PCT/GB97/02388	International filing date (day/month/year) 05 September 1997 (05.09.97)

1. The following indications appeared on record concerning:		
<input type="checkbox"/> the applicant	<input type="checkbox"/> the inventor	<input checked="" type="checkbox"/> the agent
<input type="checkbox"/> the common representative		
Name and Address WILLIAM JONES (YORK) The Crescent 54 Blossom Street York YO2 2AP United Kingdom	State of Nationality	State of Residence
	Telephone No. 01904 610586	
	Facsimile No. 01904 610909	
	Teleprinter No.	
2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:		
<input type="checkbox"/> the person	<input type="checkbox"/> the name	<input checked="" type="checkbox"/> the address
<input type="checkbox"/> the nationality		
<input type="checkbox"/> the residence		
Name and Address MARKGRAAF PATENTS The Crescent 54 Blossom Street York YO2 2AP United Kingdom	State of Nationality	State of Residence
	Telephone No. 01904 610586	
	Facsimile No. 01904 610909	
	Teleprinter No.	
3. Further observations, if necessary:		
4. A copy of this notification has been sent to:		
<input checked="" type="checkbox"/> the receiving Office	<input checked="" type="checkbox"/> the designated Offices concerned	
<input type="checkbox"/> the International Searching Authority	<input type="checkbox"/> the elected Offices concerned	
<input type="checkbox"/> the International Preliminary Examining Authority	<input type="checkbox"/> other:	

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland	Authorized officer I. Britel
Facsimile No.: (41-22) 740.14.35	Telephone No.: (41-22) 338.83.38

## PATENT COOPERATION TREATY

18 MAY 98

PCT

From the INTERNATIONAL BUREAU

NOTIFICATION OF THE RECORDING  
OF A CHANGE

(PCT Rule 92bis.1 and  
Administrative Instructions, Section 422)

To:

MARKGRAAF PATENTS  
The Crescent  
54 Blossom Street  
York YO2 2AP  
ROYAUME-UNI

Date of mailing (day/month/year) 08 May 1998 (08.05.98)	IMPORTANT NOTIFICATION
Applicant's or agent's file reference FP2136(a)	
International application No. PCT/GB97/02388	International filing date (day/month/year) 05 September 1997 (05.09.97)

1. The following indications appeared on record concerning:

☒ the applicant      ☒ the inventor      ☐ the agent      ☐ the common representative

Name and Address YUN HENG CHIN Freddie Bio-Rad House Maylands Avenue, Hemel Hempstead Hertfordshire HP2 7TD United Kingdom	State of Nationality MY	State of Residence GB
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

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☒ the person      ☒ the name      ☒ the address      ☒ the nationality      ☒ the residence

Name and Address YUN HENG CHIN Freddie Bio-Rad House Maylands Avenue, Hemel Hempstead Hertfordshire HP2 7TD United Kingdom	State of Nationality MY	State of Residence GB
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

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The person listed above has been added as applicant and inventor for the US. HIGGS Victor is the lead inventor and his name should appear first on the patent.

4. A copy of this notification has been sent to:

☒ the receiving Office      ☐ the designated Offices concerned  
☐ the International Searching Authority      ☒ the elected Offices concerned  
☒ the International Preliminary Examining Authority      ☐ other:

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland Facsimile No.: (41-22) 740.14.35	Authorized officer I. Britel Telephone No.: (41-22) 338.83.38
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CLAIMS

1. A method for identifying defects in a semiconductor or silicon structure comprising exposing said semiconductor or structure to at least one high intensity beam of light characterised by a spot size of between 0.1mm - 0.5 microns and a peak or average power density of between  $10^4$  -  $10^9$  watts/cm<sup>2</sup>; and collecting luminescence from the semiconductor or structure so as to visualise and observe defects in same by production of an image.
2. A method according to Claim 1 comprising selecting the wavelength of said light so as to identify defects at a selective depth in said semiconductor or structure.
3. A method according to Claims 1 or 2 wherein the high intensity beam of light is pulsed.
4. A method according to ~~any preceding~~ claim comprising collecting luminescence from a series of focal planes.
5. An apparatus for undertaking photoluminescence imaging of a semiconductor or silicon structure characterised in that it comprises at least one high intensity light generating means which produces a beam of light having a spot size between 0.1mm - 0.5 microns and a peak or average power density of between  $10^4$  -  $10^9$  watts/cm<sup>2</sup>; a means for collecting luminescence from the semiconductor or silicon wafer and means for producing photoluminescence images of said semiconductor or structure so as to visualise and observe any defects that may be present.

6. An apparatus according to Claim 5 wherein said light generating means is provided with modulation means whereby the wavelength of said light beam can be selected.

7. Apparatus according to Claims 5 or 6 wherein said light generating means is provided with modulation means whereby the intensity of said light beam may be selected.

8. Apparatus according to Claims ~~5-7~~ wherein means is provided to enable the high intensity beam of light to be pulsed.

9. Apparatus according to Claims ~~5-8~~ wherein said light generating means is provided with modulation means whereby the frequency of said light beam may be selected.

10. Apparatus according to Claims ~~5-9~~ wherein said apparatus comprises confocal optics whereby images of said semiconductor or structure may be obtained through a series of focal planes.

From the  
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To:

MARKGRAAF PATENTS LIMITED  
The Crescent  
54 Blossom Street  
York YO24 1AP  
GRANDE BRETAGNE

PCT

NOTIFICATION OF TRANSMITTAL OF  
THE INTERNATIONAL PRELIMINARY  
EXAMINATION REPORT  
(PCT Rule 71.1)

Date of mailing  
(day/month/year)

1 1. 11. 98

Applicant's or agent's file reference  
FP2136(a)

**IMPORTANT NOTIFICATION**

International application No.  
PCT/GB97/02388

International filing date (day/month/year)  
05/09/1997

Priority date (day/month/year)  
10/09/1996

Applicant  
BIO-RAD MICROMEASUREMENTS LIMITED et al.

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.
2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.
3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translation to those Offices.

**4. REMINDER**

The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices) (Article 39(1)) (see also the reminder sent by the International Bureau with Form PCT/IB/301).

Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide.

Name and mailing address of the IPEA/



European Patent Office  
D-80298 Munich  
Tel. (+49-89) 2399-0. Tx: 523656 epmu d  
Fax: (+49-89) 2399-4465

Authorized officer

Wirth, D

Tel. (+49-89) 2399-2835





## PATENT COOPERATION TREATY

REC'D 13 NOV 1998

## PCT

## INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference FP2136(a)	<b>FOR FURTHER ACTION</b>	See Notification of Transmittal of International Preliminary Examination Report (PCT/IPEA/416)
International application No. PCT/GB97/02388	International filing date (day/month/year) 05/09/1997	Priority date (day/month/year) 10/09/1996
International Patent Classification (IPC) or national classification and IPC G01N21/64		
Applicant BIO-RAD MICROMEASUREMENTS LIMITED et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.



2. This REPORT consists of a total of 7 sheets, including this cover sheet.

- ☒ This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

These annexes consist of a total of 2 sheets.

3. This report contains indications relating to the following items:

- I ☒ Basis of the report
- II ☐ Priority
- III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- IV ☐ Lack of unity of invention
- V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- VI ☐ Certain documents cited
- VII ☒ Certain defects in the international application
- VIII ☒ Certain observations on the international application

Date of submission of the demand  31/03/1998	Date of completion of this report  11.11.98
Name and mailing address of the IPEA/   European Patent Office D-80298 Munich Tel. (+49-89) 2399-0, Tx: 523656 epmu d Fax: (+49-89) 2399-4465	Authorized officer  Meyer, F  Telephone No. (+49-89) 2399-2233 

**INTERNATIONAL PRELIMINARY  
EXAMINATION REPORT**

International application No. PCT/GB97/02388

**I. Basis of the report**

1. This report has been drawn on the basis of (*substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments.*):

**Description, pages:**

1-16 as originally filed

**Claims, No.:**

1-10 as received on 28/09/1998 with letter of 25/09/1998

**Drawings, sheets:**

1/5-5/5 as originally filed

2. The amendments have resulted in the cancellation of:

- ☐ the description, pages:  
☐ the claims, Nos.:  
☐ the drawings, sheets:

3. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

4. Additional observations, if necessary:

**INTERNATIONAL PRELIMINARY  
EXAMINATION REPORT**

International application No. PCT/GB97/02388

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**V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement**

**1. Statement**

Novelty (N)	Yes: Claims 1-10
	No: Claims
Inventive step (IS)	Yes: Claims 1-10
	No: Claims
Industrial applicability (IA)	Yes: Claims 1-10
	No: Claims

**2. Citations and explanations**

**see separate sheet**

**VII. Certain defects in the international application**

The following defects in the form or contents of the international application have been noted:

**see separate sheet**

**VIII. Certain observations on the international application**

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:

**see separate sheet**

1. Reference is made to the following documents:

- D1: R.E. Pritchard *et al.*, Semiconductor Science and Technology **8** (1993) 1166-1172  
D2: J. Bajaj *et al.*, Semiconductor Science and Technology **8** (1993) 872-887  
D3: A.C. Ribes *et al.*, Appl. Phys. Lett. **66** (1995) 2321-2323  
D4: P. Montangero *et al.*, Materials Science and Engineering **B24** (1994) 175-179  
D5: C.J.L. Moore *et al.*, Journal of Crystal Growth **103** (1990) 21-27

- 1.1. Documents D1-D4 have been cited in the International Search Report. D5 has been cited in D2.

**Section V:**

2.1. **Novelty - independent claims 1 and 5:**

D5, which is considered to represent the closest prior art, discloses (see chapter 2 "Experimental procedure") a method for identifying defects in a semiconductor or silicon structure using photoluminescence (PL) imaging and a corresponding apparatus (see Fig.2). The subject-matter of **claim 1** (method) and **claim 5** (apparatus) differs from this method/apparatus in that the semiconductor or silicon structure is exposed to a high intensity beam of light / in that a high intensity light generating means is provided with a peak or average power density of the light beam of  $10^4$  to  $10^9$  W/cm<sup>2</sup>, whereas the light beam applied in D5 had an (average) power density in the order of  $10^2$  W/cm<sup>2</sup> (80  $\mu$ W, 10  $\mu$ m spot).

D1 (see in particular Fig.1 and chapter 2 "Experiment") discloses an apparatus for spatially resolved photoluminescence (PL) of InGaAs and InGaAsP epilayers. The light source used (6 mW, 633 nm HeNe laser) could in principal provide a light beam with a power density in the order of  $10^5$  W/cm<sup>2</sup>, but the experiments failed when applying this high density. (In D1, the PL is processed through a spectrometer, but with such a high power density of the exciting beam, the line width of the PL peaks becomes too broad to be evaluated.) Thus D1 cannot be said to disclose an apparatus and a method suitable for identifying defects in a semiconductor or silicon structure with the above stated parameter. In fact, D1

teaches a reduction of the power density of the light beam by three orders of magnitude (i.e.  $10^2$  W/cm<sup>2</sup>) which then lies well outside the range of power densities claimed in the present invention. In addition, D1 cannot be said to disclose production of a (PL) image: Although taking spectral data at many points to form a 2D image is theoretically possible, it is not taught by D1.

D2-D4 all describe PL imaging of semiconductor samples using a scanning laser microscope, but in none of the documents has the applied light beam been specified.

The subject-matter of **claims 1 and 5** thus satisfies the requirements of Article 33(2) PCT.

## 2.2 Inventive step - independent claims 1 and 5:

Starting from D5, the **problem to be solved** by the present invention is to provide a PL technique (method and apparatus) which can be undertaken at room temperature and which provides information concerning defects in a semiconductor or silicon structure more quickly.

**Solution** provided by the invention is a method and an apparatus which is not based on the evaluation of measured PL spectra but simply converts the detected PL intensity into an (PL) image in order to identify defects. As such, scanning of the sample can be performed much quicker. The defects are observed due to a change in the carrier lifetime at the site of the defect. Using the (total) PL intensity allows to apply a high intensity light beam with power densities several orders of magnitude higher than compared to the ones applied in the art since the line shape of a resulting PL peak is no longer relevant. The strongly increased power density of the applied light beam enhances the non-radiative recombination of electron hole pairs at defect sites which in turn results in an enhanced contrast in a PL image.

D5 provides no indication towards anything other than evaluating PL spectra in order to provide a (PL) image of a semiconductor or silicon structure. The skilled person would not contemplate increasing the power density of the applied light beam, since the method and apparatus in D1 (which are also used to measure PL spectra) were unsuccessful at the power density defined in claims 1 and 5. As such, the teaching of D1 actually leads away from the power density defined therein.

The subject-matter of **claims 1 and 5** thus satisfies the requirements of Article

**INTERNATIONAL PRELIMINARY  
EXAMINATION REPORT - SEPARATE SHEET**

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International application No. PCT/GB97/02388

33(3) PCT.

- 2.3. **Claims 2-4 and 6-10** are dependent on claims 1 and 5, respectively, and therefore also satisfy the requirements of Article 33(1) PCT.

**Section VII:**

- 3.1. The independent claims are not in the two-part form in accordance with Rule 6.3(b) PCT, which in the present case would be appropriate, with those features known in combination from the prior art (document D5) being placed in a preamble (Rule 6.3(b)(i) PCT) and with the remaining features being included in a characterising part (Rule 6.3(b)(ii) PCT).
- 3.2. The features of the claims are not provided with reference signs placed in parentheses (Rule 6.2(b) PCT).
- 3.3. A document reflecting the prior art described on p.2 §3 - p.3 §1 is not identified in the description (Rule 5.1(a)(ii) PCT).  
In addition, the relevant background art disclosed in the documents D1-D5 is not mentioned in the description, nor are these documents identified therein.
- 3.4. The description is not in conformity with the claims as required by Rule 5.1(a)(iii) PCT.
- 3.5. In formula (1) on p.4, a variable " $R_i$ " erroneously appears and on p.14 §3, the term "antifocus controller" makes no sense from a technical point of view.
- 3.6. On p.5 second last §, the symbol " $R_{IT}$ " has not been defined.

**Section VIII:**

4. The application does not meet the requirements of Article 6 PCT, because **claims 1 and 9** are not clear and some of the claims are not supported by the description.

- 4.1. In **claim 1**, it is not clear whether the image ("by production of an image") is produced from the collected luminescence ("PL image", p.15 §4) or e.g. from the reflected beam of light.
- 4.2. In **claim 9**, it is not clear ("the frequency of said light beam") whether the frequency of the pulsation of the beam (p.13 §4) or whether the "colour" of the light beam is meant.  
In the former case, claim 9 should have been related to claim 8 only, where a "means ... to enable a pulsed beam of light to be produced" is defined for the first time.  
In the latter case, claim 9 would be superfluous since, with the general correlation  $c = \lambda \cdot f$  (c: velocity of light,  $\lambda$ : wavelength of light, f: frequency of light), the analogous feature has already been defined in claim 6.  
Analogous obscurities arise in the description on p.9 §2,4 and on p.12 §1 ("to select the frequency and wavelength of the lasers").
- 4.3. On p.9 §5, some of the features of independent **claim 5** are stated whereas the used wording "a further preferred embodiment" implies a dependent claim to be described. This inconsistency obscures the scope for which protection is sought.
- 4.4. The wording on p.8 §1 - p.10 §1 of the description reflects the **claims 2-4, 6,8 and 9** only roughly whereas **claims 5 and 7** are not supported by the description at all.

## PCT

## INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference <b>FP2136(a)</b>	<b>FOR FURTHER ACTION</b> see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. <b>PCT/GB 97/ 02388</b>	International filing date (day/month/year) <b>05/09/1997</b>	(Earliest) Priority Date (day/month/year) <b>10/09/1996</b>
Applicant  <b>BIO-RAD MICROMEASUREMENTS LIMITED et al.</b>		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 4 sheets.

☒ It is also accompanied by a copy of each prior art document cited in this report.

1. ☐ Certain claims were found unsearchable (see Box I).
2. ☐ Unity of invention is lacking (see Box II).
3. ☐ The international application contains disclosure of a **nucleotide and/or amino acid sequence listing** and the international search was carried out on the basis of the sequence listing
  - ☐ filed with the international application.
  - ☐ furnished by the applicant separately from the international application,
    - ☐ but not accompanied by a statement to the effect that it did not include matter going beyond the disclosure in the international application as filed.
  - ☐ Transcribed by this Authority

4. With regard to the **title**,
  - ☐ the text is approved as submitted by the applicant
  - ☒ the text has been established by this Authority to read as follows:

**APPARATUS AND METHOD FOR DETECTING MICRO DEFECTS IN SEMI-CONDUCTORS**

5. With regard to the **abstract**,
  - ☐ the text is approved as submitted by the applicant
  - ☒ the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this International Search Report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is:

Figure No. 9

- ☐ as suggested by the applicant.
- ☒ because the applicant failed to suggest a figure.
- ☐ because this figure better characterizes the invention.

☐ None of the figures.



## Box III TEXT OF THE ABSTRACT (Continuation of item 5 of the first sheet)

The invention relates to a method and apparatus for detecting defects in a semiconductor or silicon structure at room temperature, and in an efficient time, using photoluminescence. The invention employs the use of a high intensity beam of light preferably having a spot size between 0,1 mm - 0,5 microns and a peak or average power density of  $10^4$  -  $10^9$  w/cm<sup>2</sup> with a view to generating a high concentration of charge carriers, which charge characters detect defects in a semiconductor by interacting with same. These defects are visible by producing a photoluminescence image of the semiconductor. Several wavelenghts may be selected to identify defects at a selective depth as well as confocal optics may be used.

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 97/02388

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 G01N21/64 //G02B21/00

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>BAJAJ J ET AL: "SPATIALLY RESOLVED CHARACTERIZATION OF HGCDTE MATERIALS AND DEVICES BY SCANNING LASER MICROSCOPY" SEMICONDUCTOR SCIENCE AND TECHNOLOGY, vol. 8, no. 6S, 1 June 1993, pages 872-887, XP000403224  see abstract  see page 873, right-hand column, paragraph 2; figure 1  see page 877, right-hand column, paragraph 2 - page 878, right-hand column, paragraph 2; figure 7</p> <p style="text-align: center;">--- -/--</p>	1, 3, 5-8, 10

☒ Further documents are listed in the continuation of box C.

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European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax: (+31-70) 340-3016

Authorized officer

Scheu, M

## INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 97/02388

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PRITCHARD R E ET AL: "COMPOSITION ASSESSMENT BY SPATIALLY RESOLVED PHOTOLUMINESCENCE OF INGAAS AND INGAASP EPILAYERS GROWN ON RECESSED INP SUBSTRATES" SEMICONDUCTOR SCIENCE AND TECHNOLOGY, vol. 8, no. 6, 1 June 1993, pages 1166-1172, XP000400529 see page 1167, left-hand column, paragraph 3 - right-hand column, paragraph 1; figure 1 ---	1,5,10
A	RIBES A C ET AL: "PHOTOLUMINESCENCE IMAGING OF POROUS SILICON USING A CONFOCAL SCANNING LASER MACROSCOPE/MICROSCOPE" APPLIED PHYSICS LETTERS, vol. 66, no. 18, 1 May 1995, pages 2321-2323, XP000507592 see the whole document ---	1,4,5,10
A	MONTANGERO P ET AL: "OPTICAL-BEAM-INDUCED CURRENT AND PHOTOLUMINESCENCE TECHNIQUES FOR LOCALIZATION OF CRYSTALLOGRAPHIC DEFECTS IN OPTOELECTRONIC DEVICES" MATERIALS SCIENCE AND ENGINEERING B, vol. B24, no. 1/03, 1 May 1994, pages 175-179; XP000445055 see page 175, right-hand column - page 176, left-hand column, line 2; figure 1 -----	2,4,6,9

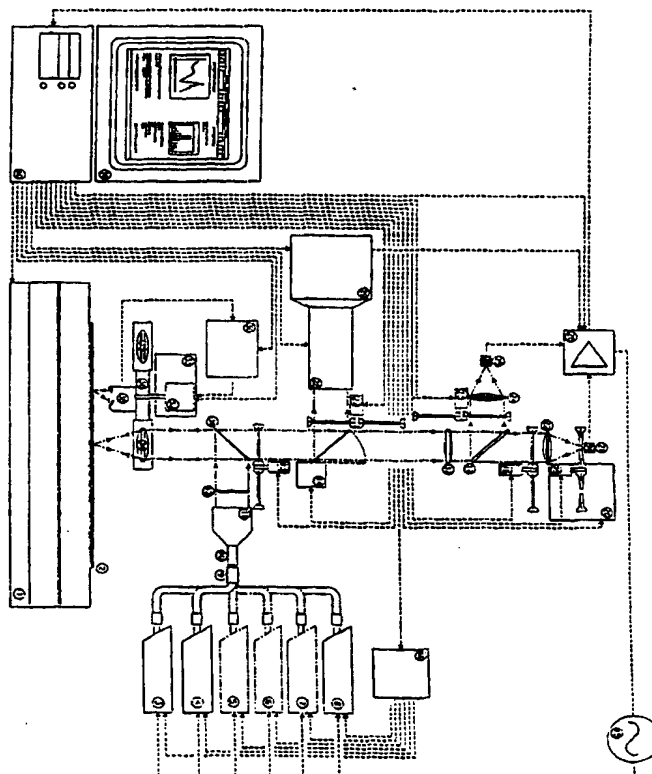
## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>6</sup> : <b>G01N 21/64 // G02B 21/00</b>		<b>A1</b>	(11) International Publication Number: <b>WO 98/11425</b>
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(21) International Application Number: PCT/GB97/02388 (22) International Filing Date: 5 September 1997 (05.09.97) (30) Priority Data: 9618897.4 ✓ 10 September 1996 (10.09.96) GB (71) Applicant (for all designated States except US): BIO-RAD MICROMEASUREMENTS LIMITED [GB/GB]; Bio-Rad House, Maylands Avenue, Hemel Hempstead, Hertfordshire HP2 7TD (GB). (72) Inventors; and (75) Inventors/Applicants (for US only): MAYES, Ian, Christopher [GB/GB]; Bio-Rad House, Maylands Avenue, Hemel Hempstead, Hertfordshire HP2 7TD (GB). HIGGS, Victor [GB/GB]; Bio-Rad House, Maylands Avenue, Hemel Hempstead, Hertfordshire HP2 7TD (GB). (74) Agent: WILLIAM JONES (YORK); The Crescent, 54 Blossom Street, York YO2 2AP (GB).		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).  Published With international search report.	

(54) Title: APPARATUS AND METHOD FOR DETECTING MICRO DEFECTS IN SEMI-CONDUCTORS

## (57) Abstract

The invention relates to a method and apparatus for detecting defects in a semiconductor or silicon structure at room temperature, and in an efficient time, using photoluminescence. The invention employs the use of a high intensity beam of light preferably having a spot size between 0,1 mm-0,5 microns and a peak or average power density of  $10^4$ - $10^9$  w/cm<sup>2</sup> with a view to generating a high concentration of charge carriers, which charge characters detect defects in a semiconductor by interacting with same. These defects are visible by producing a photoluminescence image of the semiconductor. Several wavelengths may be selected to identify defects at a selective depth as well as confocal optics may be used.



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## APPARATUS AND METHOD FOR DETECTING MICRO DEFECTS IN SEMI-CONDUCTORS

The invention relates to an apparatus and method for detecting micro defects in semiconductors or silicon and particularly, but not exclusively, in part-processed or bulk silicon.

Developments in crystal growth have enabled the production of silicon wafers free from dislocation. However, dislocation free wafers may not be able to remain this way after the wafers are subjected to high temperature processing.

Defects formed within the device active region in the wafer and defects produced in the gate oxide generally degrade device performance, lead to yield losses and reliability problems. This invention can be used to locate and measure the electrical activity of these defects.

Transition metals, which are fast diffusers in silicon, readily form deep levels, ie away from the valance or conduction band edge, and also lead to decoration of both point and extended defects which eventually lead to device failure. These transition metal impurities also form recombination centres and traps which can dramatically reduce carrier lifetime and can also act as dark current generation sites, i.e. in the absence of light, charge leakage will occur. Gettering techniques, where mechanical damage, such as abrasion, is typically undertaken in order to provide a damaged site, which effectively acts as a sponge soaking up impurities in the wafer, have been developed to remove transition metal impurities from the device active areas. It therefore follows that the aforementioned damage is deliberately targeted to an area in the wafer remote from the electrical device. Thus internal gettering techniques introduce

defects in the silicon substrate which attract unwanted impurities away from the device areas. Gettering sites need to be characterised to control their distribution for different process conditions, a task which can be performed with the present invention.

Epitaxial silicon, that is the deposited uppermost layers of silicon, typically in the order of microns thick, has been used to overcome problems with as-grown CZ wafers. In other words, as the thickness in the epitaxial silicon increases, given that this layer can be grown in a defect-free manner, it can be used as a site for the electric device without fear of contamination in the bulk wafer affecting the activity of the device. However it is not always possible to use an epitaxial layer of sufficient thickness for this activity and where the epitaxial layer is thin then defects in the bulk wafer can interfere with the electrical device. Moreover, epitaxial layers suffer from problems of metal contamination.

Several techniques already exist for the detection of defects in as-grown material, these include wet chemical etching in order to reveal flow pattern defects; light scattering topography where the topography of the surface wafer is examined using light to detect undulations which in turn are indicative of defects in the sub-structure; and transmission interference contrast microscopy where the transmission of light through the wafer is examined and the phase shift due to small path changes is used to image defects in the wafer. All of these techniques are used to measure the physical presence of defects in the wafer. However they do not measure the electrical properties of the defects and moreover in some cases they are destructive. Accordingly, as techniques for determining the structural integrity of a wafer they are lacking in terms of the

information they provide and moreover they can be positively destructive. Photoluminescence (PL) spectroscopy is a very sensitive technique for investigating both intrinsic and extrinsic electronic transitions at impurities and defects in semiconductors. When silicon is excited at low temperatures with laser irradiation above the band-gap of the material, electron hole pairs are produced. These carriers can recombine in various different ways, some of which give rise to luminescence. The electron hole pairs formed at low temperature can be trapped at impurities in silicon and they emit photons characteristic of this interaction, thereby giving impurity specific information in the photoluminescence spectra. There are a significant number of applications of PL spectroscopy to silicon including characterisation of silicon after different processing steps, characteristic of device fabrication for example implantation, oxidation, plasma etching, the detection of point defect complexes and the presence of dislocations. One of the most important applications includes the non-destructive measurement of shallow donors and acceptors such as arsenic, boron and phosphorous. Notably, this technique enables the measurement of the concentration of these shallow donors and acceptors. However, in all these applications in order to obtain this spectral information and unambiguous chemical identification of the optical centres, measurements need to be carried out at liquid helium temperatures. It is known throughout the industry that at room temperature the PL signal is significantly weakened and very little useful spectral information can be obtained.

We are aware of one set of experiments only which describe use of PL spectroscopy at room temperature (Mapping of Micro Defects in Silicon Crystals by Photoluminescence at Room Temperature; Semiconductor Silicon 1990, Proceedings Volume 90-7, pages 994-1004). Although this paper



demonstrates both deep-level PL and band-edge PL are detectable in silicon wafers at room temperature it is of note that the technique used involved obtaining spectral information and so spatial resolution was constrained and the time involved was high. This effectively limits the successful use of this technology. This is unfortunate because room temperature PL is ideal for non-destructive examination of the recombination properties of defects.

However, our investigations have lead us to develop a PL technique which has industrial application in that it enables the image to be produced within minutes. Moreover, our technique also has a further added advantage in that we are able to obtain a micro image of small individual defects near to the surface of the wafer; this is in contrast to the aforementioned PL room temperature technique which tends to produce a macro view of large defect clusters deep into the wafer.

Our technique can be described having regard to the following information.

The intensity of the PL intensity  $I_{PL}$ , as a function of the laser beam position  $(x,y)$ , is given by:

$$I_{PL}(x,y)=k[AR_f\eta\Delta n d^3] \quad (1)$$

Where  $k$  is the proportionality factor to allow for experimental parameters such as light collection efficiency, detector quantum efficiency.  $A$  and  $R_f$  are correction factors for absorption losses, inside the material ( $A$ ) and reflection losses at the surface ( $R_f$ ).  $\eta$  is the internal quantum efficiency of the semiconductor,  $\Delta n$  is the excess carrier density and  $d^3$  is the volume of material

emitting light.

The defects alter the recombination properties of the carriers which is observed as a change in intensity in the PL image. We define the PL contrast  $C$ , as follows:

$$C(x, y) = \frac{I_{PL}(\infty) - I_{PL}(x, y)}{I_{PL}(\infty)} \quad (2)$$

where  $I_{PL}(\infty)$  is the intensity far away from the defect, and  $I_{PL}(x, y)$  at the position  $x, y$ .

When excess electron-hole pairs are produced in Si by above band gap excitation, recombination can either be radiative (emit light) or non radiative.

The total recombination rate is expressed by the sum of two rates:

$$R = R_r + R_{nr} \quad (3)$$

and the internal quantum efficiency,  $\eta$  of the semiconductor is given by:

$$\eta = \frac{R_r}{R_r + R_{nr}} \quad (4)$$

When the photoluminescence images are obtained any variations observed in the PL signal could be due to the spatial variations of both  $R_r$  and  $R_{nr}$ .

The recombination behaviour of the defect depends on the position of the levels in the band gap (deep or shallow) and on the carrier capture cross sections. At low injection levels the recombination rate is limited by the availability of the

minority carriers, whereas at high injection levels, where the injected charge exceeds the equilibrium carrier concentration, the recombination rate is limited by the number of traps. Therefore increasing the injection level leads to enhanced recombination at the defect.

It is therefore an object of the invention to provide a photoluminescence technique which can be undertaken at room temperature and which provides information concerning defects in a semiconductor or silicon structure at a rate appropriate to industrial use and/or which enables us to visualise defects in the upper regions of the semiconductor or silicon structure and in particular near to the surface of same.

It is a further object of the invention to enhance non radiative recombination of electron hole pairs at defects in a semiconductor or silicon structure with a view to enhancing contrast in a PL image of said semiconductor or silicon structure so as to enhance the viewing of defects in same.

In its broadest aspect the invention is based on collecting luminescence from a semiconductor or silicon structure under selected excitation conditions the defects being observed due to a change in the carrier lifetime at the site of the defect.

We therefore use a high injection level laser in the method of the invention and defects are detected due to the local change in carrier lifetime at the defect. These defects are typically observed as darkened regions at the physical position of the defect, but in some instances enhanced radiative recombination gives rise to relatively lightened regions, having regard to the background.

The recombination at the defects is enhanced by increasing the injection level so that it is not limited by the availability of minority carriers.

We believe the success of our method is, in part, due to the probing volume of our laser being small (spatial resolution 0.1-20 $\mu\text{m}$ , ideally 2-5 $\mu\text{m}$ ) and therefore localised defects have much greater effect on the measured PL intensity. We also believe our method is successful, in part, because since the excitation is focused the injected carrier density is high. This greatly increases the probability of non-radiated recombination at the defect and hence physical location of the defect.

According to a first aspect of the invention there is therefore provided a method for enhancing spatial and depth resolution in a semiconductor or silicon structure which method comprises exposing said semiconductor or silicon structure to a high-intensity laser and then determining the photoluminescence of same.

Ideally the method is undertaken for revealing defects in a semiconductor or silicon structure by improving the contrast and resolution.

Reference herein to a high-intensity laser is meant to include, without limitation, a high power density laser i.e. where regardless of the power of the laser the emittance is focused.

We have discovered that carrier diffusion lengths are greatly reduced under high injection laser conditions, the result of this is that the effective sampling depth

is largely determined by the excitation laser penetration depth which is in turn determined by the wavelength of the excitation source. By using a short wavelength near surface defects can be examined. Conversely longer wavelengths can be used to look at defects deeper in the sample.

In a preferred method of the invention we use a pulsed laser excitation source and ideally measure the luminescence images as a function of time. This means that both depth and spatial resolution are improved and can be used to obtain information on the carrier capture cross sections of the defects. Time resolved measurements can also be used to measure the effective carrier lifetime and obtain lifetime maps.

In a further embodiment of the invention confocal optics are used to obtain depth discrimination of the defects by exciting a large volume of said semiconductor with a laser and collecting images from a series of focal planes.

According to a further aspect of the invention there is provided a method for identifying defects in a semiconductor or silicon structure comprising exposing said semiconductor or structure to at least one high intensity beam of light characterised by a spot size of between 0.1mm - 0.5 microns and a peak or average power of between  $10^4$  to  $10^9$  watts/cm<sup>2</sup>; and collecting luminescence from the semiconductor or structure so as to observe defects in same.

Using either method of the invention it is possible to image defect distribution in part processed and bulk silicon. The method has application in determining defect distribution in all semiconductors and also for determining density and spacial distribution and measuring defect recombination of semiconductors.

According to a yet further aspect of the invention there is provided an apparatus for undertaking photoluminescence imaging of a semiconductor or silicon structure characterised in that it comprises a high intensity laser as herein described.

In a preferred embodiment of the invention said laser is modulatable so as to adjust the wavelength excitation of same thereby enabling a user of said apparatus to sample said semiconductor or silicon structure at different depths.

For example, a short wavelength may be used to sample near the surface of the said semiconductor or structure and a longer wavelength to look deeper into the semiconductor or structure.

In yet a further preferred embodiment of the invention said apparatus is provided with means to enable pulsing of said laser and ideally also for PL images to be obtained as a function of time.

In a yet further preferred embodiment of the invention said apparatus is provided with means for modulating said laser at high frequencies (0.1-100 Mhz) thereby enabling a user of said apparatus to sample said semiconductor or silicon structure at different depths.

In yet a further preferred embodiment of the invention said apparatus comprises a laser of a spot size of between 0.1mm and 0.5 microns and/or a power density of between  $10^4$  to  $10^9$  watts/cm<sup>2</sup>.

In yet a further preferred embodiment of the invention said apparatus comprises

confocal optics which is used to obtain depth discrimination of the defects by exciting a large volume of said semiconductor with a laser and collecting images from a series of focal planes.

An embodiment of the invention will now be described, by way of example only, with reference to the following Figures wherein:

Figure 1 is a PL image of as-grown defects in Czochralski (CZ) silicon, scan area 1mm x 1mm using the apparatus of the invention;

Figure 2 is a PL image of as-grown defects in CZ silicon after iron contamination at  $1 \times 10^{11}$  atoms.cm<sup>-3</sup>, scan area 1 mm x 1 mm using the apparatus of the invention;

Figure 3 is a PL image of oxygen precipitates in annealed silicon, scan area 1 mm x 1 mm using the apparatus of the invention;

Figure 4 is a PL image of nickel silicide precipitates in Complementary Metal Oxide Semiconductor (CMOS) processed test wafer, scan area 500  $\mu$ m x 500  $\mu$ m using the apparatus of the invention;

Figure 5 is a PL image of copper silicide precipitates in CMOS processed test wafer, scan area 100  $\mu$ m x 100  $\mu$ m using the apparatus of the invention;

Figure 6 is a PL image of copper silicide precipitates in CMOS processed test wafer, a) high injection, b) low injection, scan area 37  $\mu$ m x 39  $\mu$ m;

Figure 7 is a micrograph of Local Oxidation of Silicon (LOCOS) test structure, scan area  $120\text{ }\mu\text{m} \times 60\text{ }\mu\text{m}$  using the apparatus of the invention;

Figure 8 is a PL image of LOCOS test structure revealing a high density of dislocation, scan area  $120\text{ }\mu\text{m} \times 60\text{ }\mu\text{m}$  using the apparatus of the invention. The dark line on the right hand side of the image shows the region of high dislocation density; and

Figure 9 is a diagrammatic illustration of an apparatus in accordance with the invention.

Referring to the figures and firstly to Figure 9 there is shown a diagrammatic illustration of an apparatus in accordance with the invention.

The apparatus essentially comprises a PL imaging microscope which: towards the right hand side, comprises a bank of lasers 3-8; towards the bottom comprises a sample stage such as an X-Y table or R- $\Theta$  table; towards the left hand side comprises a microprocessor 40 and a display screen 39 and in the centre of the Figure there are shown various optical components for directing light through the system.

In the embodiment shown in Figure 9, six lasers are provided with a view to probing different depths in the sample. However, it is within the scope of the invention to use only one laser, or indeed to use a greater number of lasers. In any event, at least one of the lasers is a high intensity laser and ideally has a spot size of between 0.1 mm and 0.5 micron and a power density of between  $10^4$  to  $10^9$  watts/cm<sup>2</sup>. A laser selector 16 coupled with said bank of lasers is



provided so as to select one or more lasers for use and further also to select the frequency and wavelength of the lasers.

Conventional optics, such as optical fibres 9 are used to direct light towards the collimator to 10 and laser beam expander 11. An apodization plate 12 is positioned between laser beam expander 11 and beam splitter 31. Beam splitter 31 directs a fraction of light from the aforementioned lasers towards sample 2 via objective 34.

An automatic focus controller 30 is provided and coupled to a piezo driven focusing stage 33. The microscope is equipped with a conventional rotating turret 36 which is provided with at least one high numerical aperture objective for micro examination and one low numerical aperture objective for macro examination 34,35 respectively. In addition, also coupled to turret 36 there is provided an optical displacement measuring system 38.

Cabling is provided so as to connect the automatic focusing controller 30 to microprocessor 40 and also a microscope objective indexing arrangement 32 to microprocessor 40.

Downstream of beam splitter 31 there is provided as filter wheel 13 for laser notch filters, down stream thereof there is provided a swing-aside folding mirror 14 whose function will be described hereinafter. Aligned with said mirror 14 there is provided a filter wheel 27 for wavelength selection, and rearward thereof there is provided a zoom lenses attached to a suitable CCD 2-D array detector 29.

Infinity system compensating lens 37 is provided in the optical path foremost of cold mirror 17 which reflects light towards a further filter wheel 23 for wavelength selection and a focusing lenses 24 which is foremost of a detector 25 for UV and visible light. Detector 25 is coupled to lock-in amplifier 26. This is used to obtain a reflected image of the surfaces.

Rearmost of cold mirror 17 is provided a further filter wheel 18 again for wavelength selection, and rearmost thereof a focusing lens 22 and a further aperture wheel 19 for pinhole selection which is provided foremost of a detector 21 for detecting the luminescence.

Both the UV and visible region detector 25 and infrared detector 21 are coupled to lock-in amplifier 26.

Operation of the system is explained having regard to the following.

A range of wavelengths to probe different planes in the sample is provided by several lasers (3-8). The lasers can be modulated by a frequency generator (16) so that the signal emitted from the sample (2) can be isolated from background radiation by means of the detectors being synchronised to the laser modulation frequency by the lock-in amplifier (26). In a further embodiment, the range of wavelengths could be produced by using a tuneable laser and/or an Optical Parametric Oscillator. Each laser is connected to, and aligned with, a Multi-branch optical fibre (9) so that any or all of the lasers can illuminate the sample (2). The common end of the Multi-branch optical fibre terminates in an optical system (10) which collimates the emerging light. This optical system is aligned with a beam expander 911) which matches the laser beam's diameter to that required by the microscope objectives (34,35) above the sample (2). The

expanded beam then passes through an apodization plate (12) which distributes the optical energy evenly over the beam area.

The expanded and apodized beam is reflected by a beamsplitter (31) and passes to the microscope objectives (34 and 35). The beam is focused by a microscope objective (34 or 35) on to the sample. In the micro mode this objective is selected to focus the beam to a diffraction limited spot size. A rotating turret (36), operated by an indexing mechanism (32), permits the objective to be changed for the macro mode where a larger area of the sample can be illuminated. In a further embodiment the apodization plate (12) can be removed so that the spot for the micro mode can be made smaller to allow higher injection levels.

An optical displacement sensor (38) measures the distance to the sample and, by means of a feedback loop through the antifocus controller (30), maintains the correct spacing by means of the piezo actuated focusing stage (33).

The Photoluminescence signal from the sample is collected by the microscope objective (34) (in the micro mode) and transported back through the beamsplitter (31) and a notch filter in the filter wheel (13) which contains notch filters matched to the range of laser wavelengths. The notch filter removes any reflected laser light, passing only the Photoluminescence signal.

The folding mirror (14) is swung out of the beam allowing the signal to pass to the tube lens (37), which may be incorporated to compensate for any infinity microscope objectives which may be used, and on to the cold mirror (17). This component reflects those wavelengths below a selected cut off point

(approximately 700 nm) to the focusing lens (24) which focuses the signal into the detector (25). A filter wheel (23) in front of the detector focusing lens (24) contains filters to isolate selected wavelength bands.

The portion of the Photoluminescence signal lying in the wavelength range above the cut-off point passes through the cold mirror (17) and is similarly focused by the lens (22) into the detector (21). This signal also passes through a filter wheel (18) containing filters to isolate selected wavelength bands.

A series of pinholes of different diameters are contained in an aperture wheel (19) positioned in front of the detector (21). This aperture wheel can be moved axially by the piezo actuator (20) so that the pinholes can be positioned confocally with the desired image plane. By this means, planes at different depths in the sample (2) can be imaged to provide accurate depths information.

The electrical signal from the detectors (21,25) is fed to the lock-in amplifier (26) where it is synchronised with the modulation frequency of the laser (3-8) by means of a reference signal from the frequency generator (15). The electric signal is then fed to the central processor (40) for analysis. The PL image is obtained by raster scanning the stage. Alternatively optical scanning using galvo mirrors may be employed.

In an alternative micro mode of operation, the folding mirror (14) is swung into the beam of the Photoluminescence signal. The diverted signal passes through a filter wheel (27), which contains filters to isolate selected wavelength bands, and into the zoom lens (28). The zoom lens allows different magnifications to be used in imaging the illuminated spot on the sample (2) on to the CCD two

dimensional array (29). This allows the illuminated area of the sample (2) to be imaged at different resolutions. The electrical signal from the CCD array is fed to the central processor (40) for analysis.

Using the aforescribed apparatus of the invention investigations were undertaken in order to visualise defects in semiconductors and the results of these investigations are shown in Figures 1-8. The images are unique and cannot be obtained by any other method at room temperature. Generally, it can be seen that use of the equipment enables localisation and characterisation of defects in semiconductors. This enables one to more efficiently screen wafers for device fabrication and so safeguard against the production of defective semiconductors.

It can therefore be seen that the invention provides an apparatus and a method for imaging defects in a semiconductor or silicon structure which enables the defects to be imaged so that the density and spatial distribution of same can be determined.

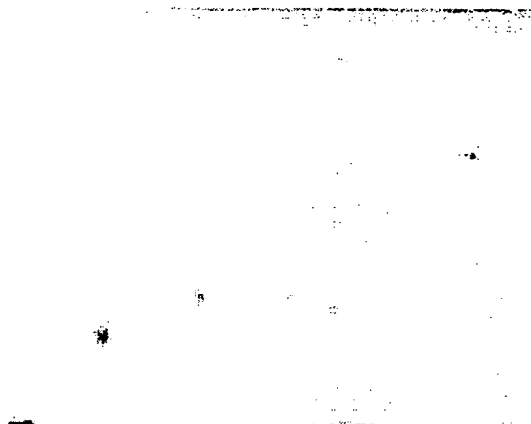
### CLAIMS

1. A method for identifying defects in a semiconductor or silicon structure comprising exposing said semiconductor or structure to at least one high intensity beam of light characterised by a spot size of between 0.1mm - 0.5 microns and a peak or average power of between  $10^4$  -  $10^9$  watts/cm<sup>2</sup>; and collecting luminescence from the semiconductor or structure so as to preserve defects in same.
2. A method according to Claim 1 comprising selecting the wavelength of said light so as to identify defects at a selective depth in said semiconductor or structure.
3. A method according to Claims 1 or 2 comprising exposing said semiconductor or silicon structure to a pulsed beam of light.
4. A method according to any proceeding claim comprising collecting luminescence from a series of focal planes.
5. An apparatus for undertaking photoluminescence imaging of a semiconductor or silicon structure characterised in that it comprises at least one high intensity light generating means which produces a beam of light having a spot size between 0.1mm - 0.5 microns and a peak or average power of between  $10^4$  -  $10^9$  watts/cm<sup>2</sup>; a means for collecting luminescence from the semiconductor or silicon wafer and means for producing images of said semiconductor or structure so as to observe any defects that may be present.

6. An apparatus according to Claim 5 wherein said light generating means is provided with modulation means whereby the wavelength of said light beam can be selected.
7. Apparatus according to Claims 5 or 6 wherein said light generating means is provided with modulation means whereby the intensity of said light beam may be selected.
8. Apparatus according to Claims 5-7 wherein means is provided to enable a pulsed beam of light to be produced.
9. Apparatus according to Claims 5-8 wherein said light generating means is provided with modulation means whereby the frequency of said light beam may be selected.
10. Apparatus according to Claims 5-9 wherein said apparatus comprises confocal optics whereby images of said semiconductor or structure may be obtained through a series of focal planes.

**Figure 1. PL image of as-grown defects in CZ Si**

**Scan area 1mm x 1mm**



**Figure 2. PL image of as-grown defects in CZ Si after Fe contamination  $1 \times 10^{11}$  atoms.cm<sup>-3</sup>**

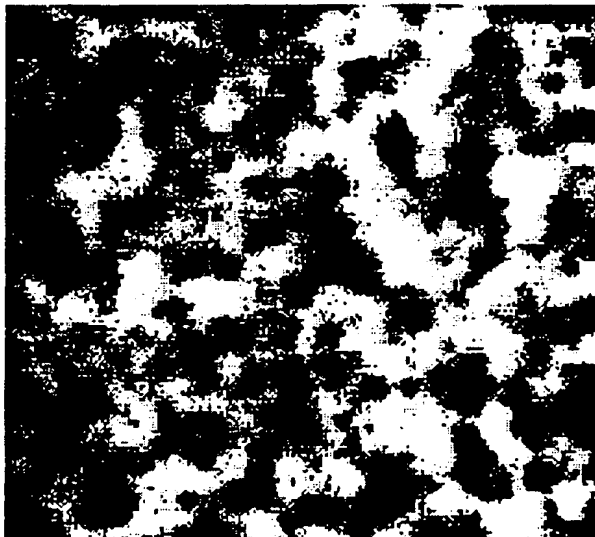
**Scan area 1mm x 1mm**





**Figure 3. PL image of oxygen precipitates in annealed Si**

**Scan area 1mm x 1mm**



**Figure 4. PL image of Ni silicide precipitates in CMOS processed test wafer**

**Scan area 500 x 500  $\mu$ m**



**Figure 5. PL image of Cu silicide precipitates in CMOS processed test wafer**

**Scan area 100 x 100  $\mu\text{m}$**



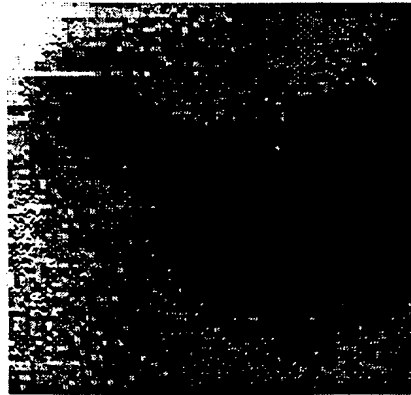
**Figure 6. PL image of Cu silicide precipitates in CMOS processed test wafer, a) high injection, b) low injection.**

**Scan area 37 x 39  $\mu\text{m}$**

**a)**

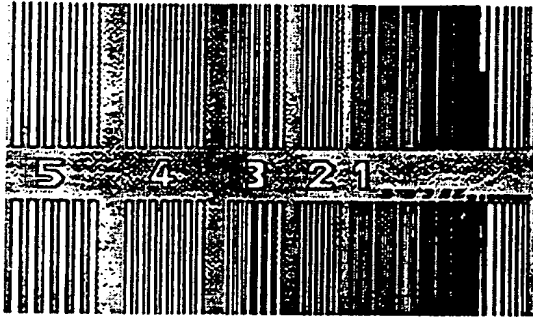


**b)**



**Figure 7. Micrograph of LOCOS test structure**

Scan area 120 x 60  $\mu\text{m}$

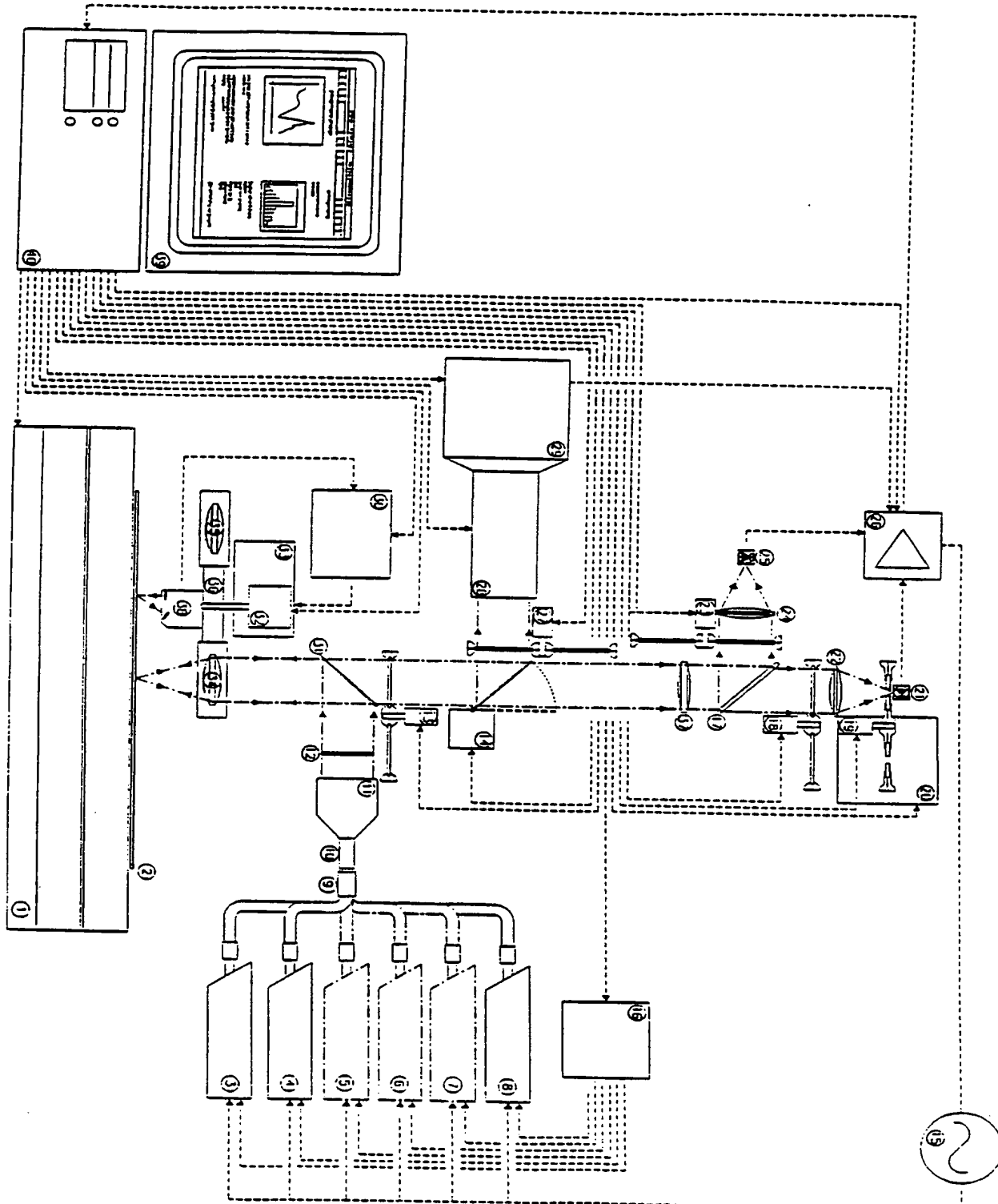


**Figure 8. PL image of LOCOS test structure revealing a high density of dislocations**

Scan area 120 x 60  $\mu\text{m}$



Figure 9



# INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 97/02388

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 G01N21/64 //G02B21/00

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>BAJAJ J ET AL: "SPATIALLY RESOLVED CHARACTERIZATION OF HGCDTE MATERIALS AND DEVICES BY SCANNING LASER MICROSCOPY" SEMICONDUCTOR SCIENCE AND TECHNOLOGY, vol. 8, no. 6S, 1 June 1993, pages 872-887, XP000403224  see abstract  see page 873, right-hand column, paragraph 2; figure 1  see page 877, right-hand column, paragraph 2 - page 878, right-hand column, paragraph 2; figure 7</p> <p style="text-align: center;">--- -/--</p>	1, 3, 5-8, 10

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

\* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search

4 December 1997

Date of mailing of the international search report

18/12/1997

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax: (+31-70) 340-3016

Authorized officer

Scheu, M

# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/GB 97/02388

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>PRITCHARD R E ET AL: "COMPOSITION ASSESSMENT BY SPATIALLY RESOLVED PHOTOLUMINESCENCE OF INGAAS AND INGAASP EPILAYERS GROWN ON RECESSED INP SUBSTRATES" SEMICONDUCTOR SCIENCE AND TECHNOLOGY, vol. 8, no. 6, 1 June 1993, pages 1166-1172, XP000400529 see page 1167, left-hand column, paragraph 3 - right-hand column, paragraph 1; figure 1</p>	1,5,10
A	<p>----- RIBES A C ET AL: "PHOTOLUMINESCENCE IMAGING OF POROUS SILICON USING A CONFOCAL SCANNING LASER MACROSCOPE/MICROSCOPE" APPLIED PHYSICS LETTERS, vol. 66, no. 18, 1 May 1995, pages 2321-2323, XP000507592 see the whole document</p>	1,4,5,10
A	<p>----- MONTANGERO P ET AL: "OPTICAL-BEAM-INDUCED CURRENT AND PHOTOLUMINESCENCE TECHNIQUES FOR LOCALIZATION OF CRYSTALLOGRAPHIC DEFECTS IN OPTOELECTRONIC DEVICES" MATERIALS SCIENCE AND ENGINEERING B, vol. B24, no. 1/03, 1 May 1994, pages 175-179, XP000445055 see page 175, right-hand column - page 176, left-hand column, line 2; figure 1 -----</p>	2,4,6,9